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Enacting Project-based Science: Experiences of Four Middle Grade Teachers

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Abstract

The case studies in this article demonstrate how 4 middle grade teachers addressed the challenges and dilemmas of enacting project-based science in their classrooms. The teachers attempted to enact several common features of project-based science, including student collaboration and ownership and the use of technology. The 4 teachers faced dilemmas with respect to balancing their use of time and content coverage with granting students autonomy. They also needed to solve the problems of addressing their district's curriculum while engaging their students in project-based science and of maintaining order as they attempted this new approach to teaching science. Project-based science was presented as a way to think about innovative instruction by providing a possible means of enactment and not a method. We found that the potential of project-based science could be realized through teachers' collaborative work with peers, enacting projects in their classrooms, and reflecting on their enactments. We also found that teachers' understanding took the form of practical, not theoretical or propositional, knowledge.

Our goal in describing the case studies in this article is to demonstrate how four teachers addressed the challenges and dilemmas of enacting project-based science in their classrooms. These case studies provide examples of teacher learning that can be used to construct a base for dissemination of innovative programs. The challenges and dilemmas the teachers faced arose from the need to teach in a manner consistent with the constructivist theory underlying project-based instruction. This theory includes four essential premises. Students (*a*) construct multiple representations of their understanding; (*b*) work on authentic, contextualized problems that are meaningful and complex; (*c*) collaborate in a com-

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munity of learners; and (*d*) use cognitive tools to construct and represent knowledge. Features of project-based instruction that embody these premises include (1) a "driving question" encompassing worthwhile content that is anchored in a real-world problem; (2) investigations and artifacts that allow students to learn concepts, apply information, and represent knowledge in a variety of ways; (3) collaboration among students, teachers, and others in the community so that participants can learn from one another; and (4) use of cognitive tools that help learners represent ideas by using technology such as microcomputer-based laboratories, graphing software, hypermedia, and telecommunications.

These features pose challenges for teachers (see Krajcik, Blumenfeld, Marx, & Soloway, 1994, in this issue). For example, how can the teacher focus instruction on a driving question rather than on several specific topics? How does the teacher help students design, conduct, analyze, and interpret investigations? Each feature of project-based science creates several challenges, as well as the overarching challenge of orchestrating the various features of project-based science. The ultimate goal for teachers is to confront these challenges in a way that is consistent with a range of practices congruent with the theory underlying project-based science.

These four cases, along with the more complete case study reported by Ladewski, Krajcik, and Harvey (1994, in this issue), illustrate how the model of teacher change outlined in Krajcik et al. (1994, in this issue) operates. The model proposes that three elements need to be addressed to promote teacher learning: collaboration, classroom enactment, and reflection on enactment. The cases reported in this article document how these three elements interacted with the teachers' knowledge and beliefs and with factors in their schools and districts—such as curriculum guidelines and resources—to affect change.

We use Richardson's (1990) concept of "warranted practice" to help interpret these cases. That is, we looked not only for changes in what teachers did in their classrooms and in their knowledge and beliefs about teaching but also for relations among knowledge, beliefs, and practice. The capability to describe these relations suggests that teachers not only can work productively with students and be conversant with important theoretical constructs but also can link actions clearly to their conceptual foundations; that is, they can provide warrants for their practices.

The Cases

The four cases presented here were selected from the work of the 11 teachers participating in our project, by using four paired criteria. First, we selected cases that represented a range of challenges in order to portray the idiosyncrasies involved in implementing innovations. Second, in contrast to the first criterion, we also wanted to describe common problems. A third criterion was to show how teachers' experiences supported the model of teacher change presented by Krajcik et al. (1994, in this issue). Finally, we wanted to show the model's limitations as the basis for teachers' learning about new programs. Although we believe that this model is widely useful to explain teacher learning, its application does not necessarily lead to uniform change for all teachers. Rather, it is a means for designing efforts to promote innovation.

The cases of Becky, Dorothy, Bill, and George follow. These are stories of experienced teachers who volunteered to take risks in order to enhance their practice. Common features of project-based science the teachers attempted to enact included student collaboration and ownership and the use of technology. All four teachers faced dilemmas with respect to balancing their use of time and content coverage with granting students autonomy. Orchestrating the features was also difficult for the teachers. These cases also show how each teacher

addressed unique aspects of enacting project-based science. For example, while one teacher worked particularly hard at using the driving question to link activities in projects, another emphasized designing and using artifacts. The teachers' experiences also show the benefits of information-sharing and support functions of collaboration with peers and university faculty and staff. As well, the cases show that the model of teacher change had different effects on the four teachers.

Fostering Pupil Collaboration and Investigation: Becky

Like many teachers who have numerous commitments outside the classroom, Becky initially hesitated when asked to participate in the project. She eventually was convinced to join by a colleague and by memories of rewards from previous peer collaborations. From her interview responses and comments she made early in the collaboration, it was clear that her major motivation for becoming involved in this work was her eagerness to get students thoughtfully engaged in learning science by immersing them in ideas that were meaningful to them and their lives. This led her to focus on the project-based science features of student ownership and collaboration.

Becky is an experienced teacher with a master's degree in reading who had taught middle-school science successfully despite her limited background in the subject. The last science course she had taken was in high school. Becky tightly structured the content, direction, and pace of lessons. In her case report, she referred to this structuring as "control": "I am a control person and usually have my whole unit planned before I begin." Becky was well organized; she planned carefully and was conscientious about meeting obligations.

Becky faced three major challenges during the year: (1) How would she promote collaboration by establishing groups and norms, sustaining students' focus on a problem, and holding students accountable for participation? (2) How would she encourage students to see a problem as authentic and to take ownership of it? (3) How would she help students conduct investigations?

The setting. Becky teaches in a middle school in a relatively affluent college town with a population of about 110,000. The district, serving a predominantly white, middle-class community (about 25% minority), has five middle schools with about 800 students each. Becky's school serves students from two areas of subsidized housing and the entire university housing area for graduate students with families. This results in a diverse mix of low- and middle-socioeconomic-status students, many foreign students, and many students from single-parent families. Within the school, interdisciplinary teams work with approximately 50 students. In Becky's team situation, she also taught social studies to the same students, so that she had some scheduling flexibility to extend class periods when needed. Class size in this school is relatively small; Becky's class consisted of 24 sixth-grade students.

Initial attempts at project-based instruction. Instruction during the beginning of the first science project reflected Becky's emphasis on organized teaching along with her belief in the importance of covering the prescribed science curriculum. Becky's initial attempt at enacting the features of collaboration, ownership, and investigation occurred within her general scheme for classroom teaching, in which lessons were carefully constructed, activities designed, and student roles predetermined. Becky referred to her need for "control of lessons." One way to view Becky's approach is as a desire for two types of order (see Doyle, 1986): (*a*) to create a smooth and predictable flow of events and (*b*) to determine the content and pace of lessons to ensure curriculum coverage and student learning.

Becky found that having students conduct investigations collaboratively threatened classroom order and created a dilemma over the extent to which she would

let the students pursue their investigations if their work took them away from the established curriculum. Fostering investigations and engaging students collaboratively are closely related problems; as teachers work on one feature they inevitably become entangled in the other. For instance, the purpose of collaboration is for students to work together while exploring the driving question, yet when Becky tried to promote collaboration, she did not have strategies to advance collaboration *and* to keep students focused on their investigation.

One activity for the class was to write a letter about their community to send via telecommunications to students in other schools in nearby states and across the country that were on their "research team" (a research team is composed of a dozen or more classrooms throughout the country and world that participate during the same period on the same Kids Network project). The purpose of the letter was to focus students on the sources of their school's water and local characteristics like geography, industry, and agriculture that might affect the content and quality of the water. The activities used to write and communicate the letter were designed to have students use technology to go "beyond the classroom walls."

Despite its potential, the letter-writing activity was not collaborative, and its role in making sense of the investigations of the driving question was not emphasized. Instead, Becky was concerned with getting through activities as suggested in the teacher's manual and struggling with time pressures. She began this activity by telling all students to write their own versions of the letter, even though they were working in small groups. A student asked Becky whether her letter would be sent out. When Becky said no, the student asked for an explanation, to which Becky replied, "Because I said so." Later Becky wrote the letter for the class and sent it via electronic mail, thus missing an opportunity to explore important content and promote student collaboration and ownership.

A similar situation occurred during an investigation in the *What's in Our Water?* project (National Geographic Kids Network, 1991). Here, Becky's commitment to cover curriculum in a limited time interfered with authentic investigations being pursued to their conclusion. When students were investigating the effect of chlorine on the growth of yeast, the class was to complete three observations 10 minutes apart and then discuss their findings. The purpose was to help students understand water treatment by examining the effects of chlorine on microorganisms. As the class drew to a close, only two observations had been completed, and Becky told the students to clean up. The next day, students did not discuss what they had seen. Again, Becky's need to cover content and move to the next activity took precedence over having students interpret data and consider how results related to the driving question.

At this point in the science project, Becky's teaching reflected a dilemma that resulted in a growing sense of frustration. Her agreement to work on project-based science was based on a strong motivation to promote thoughtful student learning of important ideas. She understood that such learning is best accomplished by fostering student autonomy and responsibility. Yet she also believed it was essential to cover the content specified in the district curriculum. As the first few weeks of project-based science unfolded, Becky sensed that she was not yet successful at promoting student engagement with scientific ideas and student responsibility for learning. She had yet to learn how these could be accomplished in project-based science. In her attempts to engage students in activities and to cover the curriculum, her teaching started to appear choppy. She had lost the smooth flow of activities to which she was accustomed. In a sense, Becky, a highly experienced, even expert, teacher, was once more a novice who suffered the problems and doubts of the novice.

In her case report, Becky voiced her frustration at this point. She described her reaction to the telecommunications letter discussed previously: "I gathered the information and transmitted it myself without involving students. This is not the way to do it because it is important to involve the students from the very beginning for them to have ownership, that is, believe in their involvement, but I was just trying to keep my head above water." The struggle she faced between fostering significant science learning versus getting through the curriculum is evident in another statement written in her journal early in the first term: "At times I was hurrying so fast to keep up . . . that I was going on to the next lesson even though the students were still interested in the last lesson or still had questions about it or didn't understand it."

In early work sessions, Becky thought that none of her peers was struggling as she was in enacting a project-based approach because few teachers at this point were discussing their problems with the group. Though some discussed their initial frustrations with the use of technology (a safe disclosure because using the computer was so evidently difficult for most of the teachers), few alluded to the substantial difficulties with classroom enactment that finally emerged during the fifth work session in late November. Her frustrations, along with her lack of awareness of others' difficulties, combined to make Becky feel incompetent as a science teacher, a new and unwelcome change in her professional self-esteem.

When her peers and the university staff offered information or ideas, Becky used them without modification. In her case report, she reflected on this: "This is because with my personality I find myself trying to do everything exactly as directed." She contributed suggestions for the work sessions and helped organize the calendar for the year's work, but her interactive style was to listen and occasionally ask clarifying questions; she even sat apart from the group many times.

Becky's unwillingness or inability to modify activities to suit her own classroom setting probably stemmed from two sources. First, her limited knowledge of the content led her to view others as content experts and made it difficult for her to evaluate whether activities suggested by those she viewed as content experts or by the curriculum illustrated key science content. Second, she had not yet developed a coherent vision of how project-based science worked. By necessity, she had to plan and enact projects by using her existing knowledge of teaching, which required well-organized and carefully planned lessons.

A growing realization. As the first unit progressed, two classroom events, in conjunction with experiences other teachers described during the work sessions, led Becky to reflect on her teaching and her beliefs. They made salient the importance of simultaneously promoting two features of project-based science, student ownership and student investigations. The first event occurred when student groups grew grass seeds to test the effects of different concentrations of fertilizer on plant growth. The goal of this investigation was to illustrate the beneficial effects of nitrate-based fertilizers on plant growth and the potentially harmful effects of nitrate runoff on water quality. As the seeds sprouted, students became very involved with their plants. Students' increasing involvement paralleled the growth of the small plants as they checked and watered them daily. Becky's observations of student involvement were supported at work sessions where other teachers described similar student reactions to the experiment.

In the second event, Becky's students began receiving E-mail letters from other classes. Other teachers had discussed at work sessions their students' excitement on receiving such communications. However, Becky did not see the same excitement in her own students, perhaps because they had not played a significant role in writing the first letter. She stated in her case report,

"I know that they missed a big piece of this project by not doing this letter themselves. . . . Then the letters from the other schools began arriving; our students didn't fully appreciate them because they hadn't composed a letter themselves." Discussing experiences and reflections with her peers enabled Becky to examine her own experiences and recognize that her focus on coverage interfered with student ownership of tasks, which at this stage she defined as following student suggestions and encouraging participation in activities.

Collaboration with peers at project work sessions not only reinforced Becky's growing realization of the need to change her thinking about teaching and learning; it provided her with ideas about new ways of teaching. Becky had not considered changing the structure of the unit before she learned of her colleagues' changes to the materials and methods. Other teachers' revelations helped Becky realize she could alter or use activities out of sequence or even skip some that did not seem to meet the needs of her class. "It helped to meet with my colleagues at the university and hear that they were skipping parts and doing some items out of order. I improved at giving myself permission to do the same." In the following excerpt from her case report, Becky summarized her reflections on the first semester: "After hearing discussions at our U. of M. sessions by other teachers and finding out that they did not do everything 'by the book' and after having been completely through the unit myself, I now can see how even with a prescribed unit, there still must be some teacher discretion about which lessons to alter."

Providing for more student autonomy as a way to foster ownership still created conflict for Becky. Although she could see that increased autonomy could lead to more student involvement in activities, she needed to think further about how to reconcile the inevitable discursions brought on by such autonomy with her sense of the need for covering the curriculum. In Richardson's (1990) terms, Becky was beginning to develop a concept of "warranted practice." She focused her reflections on the challenges of increasing collaboration among her students while maintaining their focus on the driving question and fostering student ownership. "I am beginning to take a closer look at this, and maybe I will decide it is better to develop a balance between planning and flowing with where the students take it. This is definitely an area of personal growth for me."

Juggling student ownership and collaboration. At the beginning of the second-semester project, *Acid Rain* (National Geographic Kids Network, 1989), Becky focused on encouraging student ideas, promoting involvement, and assisting students in their investigations. The events on the first day of the unit demonstrated that Becky was shifting from relying entirely on her plans to incorporating students' ideas. She continued to develop strategies to help students analyze and interpret data and to relate results of investigations to the driving question. When she introduced the project, Becky began by asking students what they knew about the topic and what questions they had. During the discussion, one student suggested an idea that Becky knew was incorrect. Nevertheless, she added the idea to the chart about acid rain that she was creating, because she thought it was important to include all student responses as a way to foster ownership. Similarly, when students raised questions that addressed areas of the content that Becky did not know, she felt that she had to honor their contributions, even though doing so distressed her. In her case report, Becky wrote about the significance of students determining the questions that would be the basis for their own learning: "I believe that the question should be, that they should own them. That they should be things that they really wanted to learn. I wanted to be safe, so that they didn't ask any questions that I didn't know the answer to and . . . [it] kind of worried me that we were getting

into something that I didn't know anything about, but I also wanted the questions to be theirs."

Becky also demonstrated her changing vision of project-based science by giving students more opportunity to shape their own investigations. For a more individualized project artifact, she encouraged students to explore their own questions about acid rain by working alone or in pairs. Some students devised a way to test the pH of a solution; others gathered additional information about acid rain from organizations such as the Environmental Protection Agency. One student took a more activist role, circulating a petition in his neighborhood to halt the construction of what he believed would be an acid-producing factory.

Becky's changing approach to teaching is exemplified by an investigation, an exploration of the effects of rain of various pH on the growth of bean plants, that she and the class conducted early in the second unit. This investigation became a vehicle for students to express their ideas and assume responsibility. The unusual aspect of this activity was that students completely determined the protocol, a major departure for Becky. She facilitated student discussion of ideas about the procedures and required students to explain their suggestions. Students' involvement and autonomy were much higher in this activity than during the first project, when students were given sheets with the steps in the investigation written out and were assigned specific tasks to complete. In contrast, in the bean seed investigation, students designed and then conducted the procedures and debated what the variables and controls should have been.

The idea for the bean plant investigation came from the second work session early in the second semester at which one of the university collaborators modeled how to encourage students to collaborate. At the work session, teachers worked in small groups to investigate how acid rain affects the environment. For an hour and a half, teachers designed and began the investigation. As she had done in the first unit, Becky used science activities she learned at a work session in her own classes. In contrast to her approach in the first unit, when she applied activities without changing them, Becky now adapted the activity to the skill and interests of her students. Knowing that her students were interested in living things, Becky suggested that students focus on the growth of bean seeds. Rather than requiring each group to design an entire investigation, Becky had the whole class develop the protocol and rationale for the experiment. However, she concluded the design phase with a vote, so that all student groups would follow the same protocol.

Conclusion. After two semesters of work, Becky still found it difficult to promote student ownership. She attempted to do this by providing opportunities for students to assume more control of the direction and responsibility of learning. Her conception of student ownership and strategies for achieving it was still evolving. Becky had not yet developed strategies for promoting ownership in a manner that related student questions and concerns to the driving question. Moreover, as her case report reveals, she had not yet resolved a basic dilemma: "One has to struggle to not let their preset deadlines and guidelines drive the curriculum and remember to provide the students an opportunity to have ownership of the project and give importance to their questions." Nevertheless, through collaboration with peers, reflection on videotapes of her classroom, and in her case report, Becky's views of the possibilities of project-based science grew; her beliefs underwent considerable transformation; and her instruction, especially with respect to student involvement, moved in the direction of practices congruent with the premises of project-based science.

Using the Driving Question with Collaboration: Dorothy

For Dorothy, the prospect of learning new approaches to instruction was exciting.

The uncertainty and insecurity of using unfamiliar instructional strategies were outweighed by her desire to see students improve as learners. Her interest in empowering students as learners convinced her to face the challenges she saw as inherent in this program. According to Dorothy, "This was a chance for my students to learn how real scientists work . . . to learn that there doesn't always have to be one right answer. Sometimes investigations can just lead to more questions. Students could broaden their horizons by communicating with people outside of their normal range of experience."

Dorothy had been involved in instructional innovation for a number of years prior to joining the project-based science effort. The previous year she had begun a new and fairly rigorous engineering program with one of her seventh-grade classes. This was in addition to a preengineering program, involving an in-depth study of motion, that she was already teaching to her fifth graders. She was excited at the prospect of introducing project-based instruction to her sixth graders.

Although she was an elementary science-education specialist, Dorothy knew little about project-based science and topics related to water. However, she had experience with hands-on science and readily agreed to participate in the program. She was familiar with conceptions of teaching that incorporate significant student involvement, but she was not familiar with the project-based science concept of the driving question as a means for linking student activities and investigations to important science content. She felt uneasy at the prospect of mastering an unfamiliar computer system and worried about using only one computer for 30 students. However, she understood that she and the other teachers could expect considerable support from the university staff with the computers and other materials and information needed to implement the two projects.

Dorothy's concerns became evident at one of the first work sessions, when the teachers viewed a videotape to acquaint them with project-based science. The video showed some students in small-group discussion, other students using computers, and still others working on experiments. Each group appeared to be working independently. The teachers in the video appeared at ease with the variety of activities occurring around them. Dorothy was accustomed to working with groups but only when all were doing the same activity. Her first impression of the video was that she had taken on a daunting task at which she might not succeed. As she watched the video and considered what she had learned so far about project-based science, she identified three areas of concern: (1) How would she promote collaboration by establishing groups and norms, sustain focus on the problem, and hold students accountable for participation? (2) How would she develop proficiency in the use of the technology and help students use the technology for investigation, collaboration, and artifact development? (3) How would she develop the driving question so that it involved significant science content?

The setting. Dorothy had taught science for 13 years at a K–7 elementary school in Detroit. The school serves a working-class community in suburban Detroit and has a minority enrollment of approximately 25%–30%. Dorothy had worked on the revision of the state objectives in elementary school science and had given many presentations at local, state, and regional meetings of professional associations. She had also supervised workshops for her district, demonstrating programs for integrating math and science with hands-on activities. Although Dorothy currently taught science to fifth-, sixth-, and seventh-grade classes, she had also taught science to younger students in the school. As a result, most students in her current sixth-grade class had been in Dorothy's science classes previously.

Initial attempts at project-based instruction. As Dorothy began to think about how she would enact project-based science, she focused on developing strategies for promoting student collaboration. Although her students had worked in groups, the groups always worked on the same task, and movement around the room was limited. She was uncomfortable with students engaging in different tasks at the same time and with the possibility that they might not learn the content she thought was important. As she stated in her case report, "I had never worked [with] groups where different students were doing different things all at the same time. I didn't think I would be able to do that. How could you possibly monitor the students effectively? I couldn't see how we would have time for all of this individualized study." Adding to these concerns was the fact that she only had students for three 50-minute periods a week, limiting her ability to carry activities over to another day.

Dorothy wanted to make sure that her students would engage thoughtfully in science activities and that they would all have opportunities to learn. She understood early that sustaining students' involvement while providing them with opportunities for collaboration would be difficult. From her previous experience with small groups, she knew that the students might disengage when the work became difficult or when tasks were ambiguous. Thus, Dorothy began her work on project-based science with a knowledge of some of the serious impediments to enactment. In Dorothy's early attempts to have students collaborate, she made two important discoveries. First, she discovered that students had many interesting questions about the natural and social world that were applicable to science teaching and learning. This discovery sustained her interest in the current innovation. But the second discovery created a paradox for her. She found that some of her teaching had led to student knowledge that was inert—knowledge that did not enable students to use their understanding to develop an investigation. This was a sobering realization for Dorothy that could have discouraged her from using project-based science.

This paradox emerged when, following a suggestion in the teacher's guide, Dorothy introduced *What's in Our Water?* by asking students to list the uses of water in order of importance. The resulting lists were all similar and failed to stimulate thoughtful classroom exchange. To promote a more thoughtful discussion, Dorothy asked students to consider the effects of drought on water usage. Working in small groups, students were to discuss this issue and revise their lists. However, Dorothy was disappointed in the lack of enthusiasm and critical thinking. She found that there was "very little exchange of ideas or examples of independent thought. Some students didn't participate at all in the discussion or even in writing. They either stared off into space or had their own unrelated conversations. Later, as each group presented their lists, the presentations became shorter and shorter. Students seemed to feel that the 'right answers' had already been given and there wasn't anything else to say."

Dorothy did not know at this point how to overcome students' limitations. As she thought about the outcome of this activity, she realized that students "didn't seem to know how to discuss or share ideas. They just accepted whatever the most outspoken students said and agreed with them." She realized that, although students were excited about the project, they were most intrigued by the prospect of using the computer. She also realized that the students were not prepared to find solutions to the problem of water pollution—that, in fact, they did not believe a problem existed. They were unconcerned because they thought all pollutants were filtered from their drinking water.

Because Dorothy was committed to fostering student thoughtfulness and to teaching important science content, she viewed

this as an opportunity to change her instruction instead of excusing inaction. She also realized that the features of project-based science, such as collaboration and the driving question, were closely intertwined. She saw that, when students began to collaborate, they lost sight of the importance of the driving question and did not yet know how to go beyond easy responses to significant questions.

In response to the double challenge of enacting collaboration and linking students' work to the driving question, Dorothy rethought her strategy for engaging students in thinking about content. In her own words, she decided to "take my cue from my students." Because the students seemed convinced that filtration was the answer to the water pollution problem, Dorothy decided to tell them a story about how the Detroit River became polluted. As she did, she dramatized the pollution of the river by adding "pollutants" such as wood chips, food coloring, and oil to a container of clear water. Each student group then set up a filtration system by using a funnel, gravel, and some cotton and filtered a sample of the polluted water. As the students performed this task they discovered that the food coloring and some of the oil passed through their filter. The students became concerned about what might be in the water they drink. Dorothy's triumphant reply was "that's what we want to find out in this project." Thus, although Dorothy's introduction to project-based science came from "the university staff, the prepared curriculum, and from the other teachers on the team," she thought that both she and her students "gained the most valuable information about project-based science by doing project-based science."

Refining enactments. As Dorothy moved to the next project, *Acid Rain*, she found that her hard work and her students' efforts during the first unit had produced gratifying results. Bringing the driving question into each day's lesson and linking it to activities and investigations had now become "almost second nature" to Dorothy. The students had become so accomplished at researching prior information that they were applying concepts they had learned in the previous unit to explain new information and develop new concepts in the acid rain unit. For her this was a startling result, considering that "some of these same students couldn't remember what we did from one day to the next when we started project-based science in the fall."

Another benefit of project-based science was evident as the students began their research of the new problem area. When the class had begun the water unit, the students had required considerable assistance and direction in using resource materials. As the students began research related to their study of acid rain, they demonstrated a new ease in their use of the various resources available in their classroom (e.g., books, magazines, and each other) and often asked to go to other classrooms to obtain additional references. Students brought newspaper and magazine articles from home that contained information pertinent to their investigations, and some went to the public library. One student found a lengthy newspaper article that discussed the effects of water pollution on different species in the food chain. His presenting this information to the class prompted a detailed and animated discussion of how microorganisms were exposed to pollution and what other species could be affected as a result. In another instance, student teams had been formally debating the effects of water pollution. Although the debate officially ended on Friday, the following Monday one student came to class with several pages of information he had gathered from reference books at the public library in support of his team's position. He was given the opportunity to summarize his findings and pass around his folder containing the information he had written.

As Dorothy pointed out, this kind of independence and productivity "did not happen overnight." It required considerable di-

rection and intervention on her part during the first project. But as the *Acid Rain* project progressed, she found the students becoming increasingly independent and taking more active roles in their learning, both individually and as groups.

Dorothy could also see growth in her students' ability to collaborate. She saw greater participation in both the small-group discussions and decision making, during which "even some of the slowest students contributed." As students became more responsible for their own learning, group work resulted in better comprehension of science. Students more often applied information learned from earlier discussions to explain data they collected in subsequent investigations. As a result of her students' increased facility with resource materials and collaboration, Dorothy found that she spent less time directing and monitoring these activities.

Conclusion. Dorothy understood early in the year that she would need to focus on having students work collaboratively. She entered this effort with beliefs and experiences that were consistent with the premises of project-based science, yet she approached her teaching with a focus on order that did not allow students to become autonomous learners. Through her early enactments, it became clear to her that student collaboration would have to focus on the driving question. To accomplish this, she developed strategies that supported students' efforts. When a student came to class with an interesting and well-researched issue to present to the class, she incorporated the idea into the day's activities. Thus, she not only honored the student's ideas, she helped other students see the value of independence and the need to think through questions systematically and thoroughly.

Dorothy also acknowledged the value of peer collaboration and discussion. The opportunity to meet with other teachers to discuss the ramifications of this new approach to science instruction allowed Dorothy to become more comfortable working with this program. As the first year progressed, she continued to benefit from this support from other teachers that helped her resolve problems in the course of the units.

Barriers between Beliefs and Practices: Bill

Bill began the collaboration with a solid knowledge of project-based science. He had participated in several efforts at teaching project curricula sponsored by other education agencies and was viewed by teachers and principals in his district as an expert on projects. He had tutored others in this approach and in using the technology. During the first year of our work, Bill field-tested several projects for the Technical Education Research Center. He frequently discussed his experiences during collaborative work sessions, was quite articulate about premises underlying the approach, and eagerly offered suggestions for implementation.

Bill's interest in participating in our project was primarily related to his long-standing reputation as an instructional innovator; he wanted to advance his competence as a teacher of project-based science. Specifically, he wanted to learn how he could select artifacts that were both rich and feasible so that students could develop meaningful understandings and how he could use these artifacts to assess student learning. He also wanted to learn how to help students use technology for investigation, collaboration, and artifact development.

Addressing these challenges required Bill to reflect on his approaches to using technology and artifacts. The difference between our project and previous ones in which he had participated was that ours involved an attempt to develop a range of congruent practices consistent with constructivist theory, using two National Geographic Society curricula as a point of departure for learning how to teach projects. Bill had previously learned to use a prepared project-based curriculum and to implement it as specified. In addition, personal and school context factors made his use of

technology and artifacts more conventional than is consistent with project-based science.

The setting. Bill worked in a middle school in a relatively affluent suburb of Detroit that served neighborhoods less wealthy than the surrounding community. The school had many resources available to the teachers and students, such as a well-equipped computer lab and money for frequent field trips. The community had high expectations for its schools and placed pressure on teachers and administrators to provide quality up-to-date programs, to be accountable to parental demands, and to produce high achievement test scores.

Bill had over 20 years of science and math teaching experience in grades 5–8, although his academic background was not in science. During the study year, he taught classes in all of the middle grades. There were 22 students in his sixth-grade class, half boys and half girls, which met for a 2-hour math/science block. Bill sometimes used both hours for science. Because of his complex teaching schedule and the lack of space, Bill's classes met in different rooms throughout the school. During the first term his class often met in the computer center, where there were many Apple IIe and IIgs computers. This arrangement changed during the second term; computer resources in the classroom where he taught were more limited. Bill taught the *Acid Rain* project two or three times a week for 1 class hour during the second term. For the other hour, he taught math. On the days he did not teach the *Acid Rain* project for science, he taught a chapter on weather from the sixth-grade science book.

Facing the difficulties of using technology. Unlike several of the other teachers, who had to develop their own computer skills and learn how to use the technology with students, Bill was both skilled in using telecommunications and had a clear conception of how telecommunications could foster student collaboration, investigations, and artifact development. During work sessions he was vocal about technology, explaining its use and purposes to the other teachers. Nevertheless, Bill's practice did not match his conceptions. Sometimes, students used the computers to write summaries of what they had done in class, or they used software to locate their research team schools on a map. However, Bill did not allow students to use the computer for E-mail; instead, he sent and received correspondence over the network. For example, at the beginning of the first project, students were to develop a letter about their school and community and send it to the other classes on the research team. The purpose was to gather and exchange information about factors that might influence water content and quality. Bill organized the class into small groups, which were to write a paragraph about one piece of information needed for the letter. The class did not discuss their information, nor did they use the technology. Later, Bill composed the letter by using students' paragraphs and transmitted them via E-mail. When other classes sent their return letters and later reported data from their investigations, Bill opened the mail and retrieved and printed the letters. Moreover, he did all the telecommunication outside of class so that students did not even observe the process. As a result, receiving the data from other schools did not engender the same type of excitement other teachers reported. In most of those rooms, students played a bigger role in the process.

During the second project, Bill's use of technology changed little. In addition, students had even less access to the computers because of the room change. The four computers available were prone to frequent problems so that students used software packages less than they had the term before. Again, Bill did the telecommunications outside of class so as not to use up time.

Struggling to use artifacts. The main artifact in Bill's class was an elaborate notebook that represented what students had accomplished. The notebooks were loose-leaf binders divided into sections containing

activity sheets from the curriculum and a daily journal, which also included written or other products that the students had developed. Students decorated their covers, taking great pride in their artwork. The notebooks were similar for all students, although they did differ in that the journal section included individual and small-group ideas, predictions, questions, and analyses. Typically, Bill used the notebooks for recording information generated during class activities. For example, students copied the names and global addresses of the research team into the notebooks.

By having students record a wide variety of information and ideas, Bill ensured that the notebooks were a complete record of what was done in class for the project. Often, however, the students and Bill never referred to the information again. The class *did* use a chart of rain pH later in the project to attempt to discover a pattern in the data about when and where rain was more acidic. They also used global addresses to locate the research team schools on maps. However, as the project progressed, students never revisited their list of activities contributing to acid rain, nor did they use the description and illustration of the acid rain cycle again. Predictions and opinions also were not reexamined. Bill did not have students share, revise, or critique their artifacts, and he rarely used artifacts for linking lessons. Thus, the notebook contents were not used to integrate information in order to address the driving question or to have students represent their knowledge in a variety of ways.

Moreover, Bill stressed neatness, completeness, and organization as the basis for grades. He was uncertain how to assess student understanding from the notebooks. Although he recognized the need to develop other means of assessing learning, he focused on having students add material to the notebooks rather than rethinking his fundamental approach to the notebook as an assessment device.

Impediments to teacher learning. On several occasions Bill discussed the collaborative benefits of telecommunications, and he was quite proud of his students' notebooks. Why did he not take advantage of the opportunities afforded by project-based science, of which he was clearly aware? One reason may be that he faced the dilemmas other teachers faced: balancing curriculum coverage with providing student autonomy and struggling to accomplish as much as possible under constraints of time. Bill actually had more time and resources than many of the other teachers. He taught the same students for two consecutive class periods and, at least for the first term, had enough computers for students. Other school context factors, however, contributed to his dilemma.

One problem for Bill was that he approached project instruction separately from the regular science curriculum. He mentioned several times that, in his district, parents put considerable pressure on the school to prepare students for statewide and other standardized tests and that they were concerned with seeing traditional evidence of student learning. Because project-based instruction may involve activities tangential to the endorsed curriculum, parents might feel that their children were not learning. Indeed, Bill said that he had received calls from parents with such concerns.

Second, teachers in subsequent grades expected students to have been exposed to particular content and complained about teachers who failed to cover the textbook. Bill pointed out that not covering the expected curriculum put students at a disadvantage in their subsequent classes. He mentioned on several occasions during the first year that, although he liked doing project-based science, he was sensitive to these pressures from the school and parents.

In addition to his teaching context, personal factors, preferences, beliefs about teaching and learning, and knowledge probably contributed to the discrepancy between conceptions and practice. Like sev-

eral of the other teachers, Bill valued order. He was a neat and organized person who liked to know what was happening in his class. He carefully planned lessons and closely followed his plans. Bill was concerned with efficiency and with keeping records of his students' accomplishments.

By the end of the year, Bill recognized the discrepancy between his stated position on project-based science and his practice, but he did not confront it. Instead, he explained the discrepancy by referring to students' lack of knowledge and inability to work autonomously. He noted that students had little experience doing science other than by using the textbook. Although he understood the importance of having students develop artifacts that fostered thoughtful learning, he was reluctant to give students the time and autonomy necessary to construct their knowledge. During the end-of-year interview, Bill stated:

> I think many students have great difficulty assuming the responsibility for their own learning. . . . One of my major goals would be to have students assume responsibility for the learning that they do in the classroom, but for many students that aren't used to that, that might be very very difficult for them to achieve. If you're getting the students in the middle school and if they have had very, very little science background in previous years, if their science is only then something that takes place in little short snippets of time, is very textbook based, they might read about something and answer a few questions about that. The questions are right there in the textbook, and many times all they need to do is find the questions in the textbook and write the questions, the answers, on a piece of paper. And to them, perhaps that's science. I see that in my own classes. [They do this] because that's what they are used to. That's what they've had in previous years.

To Bill, this meant that students did not know how to learn by themselves. At one point in the second project, he gave students more opportunity for autonomy during a collaborative activity. However, he thought students were unable to work productively, and he was reluctant to try this again. Students' lack of experience with self-directed learning troubled Bill. He thought students did not have the knowledge and skill to persist in the face of difficulties and consequently would not benefit from increased autonomy to explore issues. The outcome could be disastrous for the teacher, for order could completely break down: "A lot of time we face the real potential of losing them. You can literally lose control of your classroom. Not that they would throw things and be disruptive, but after a little while if it's too open-ended, if the students had too much responsibility, many of them do shut down, and many middle grade students give up. They don't become absorbed in the investigation. They're not there. If they were, then you could let loose a little bit."

Conclusion. These beliefs echo those of many of the other teachers who struggled with giving students more autonomy and more responsibility for using the technology, for collaborating, planning investigations, and building artifacts. The teachers discussed their frustrations, successes, and strategies during work sessions in which Bill participated.

One reason Bill may not have confronted the inconsistencies in his own practice or used some of his peers' experiences to change his own enactment may have been his prior experience. That is, he came to this effort considering himself to be relatively expert in project-based science, so it might have been more difficult for him to acknowledge his difficulties and act like a novice among his peers. Also, like Becky, one possible reason for his practice of not wavering from the curriculum might be that it provided security, since he was not likely to run into unexpected content if he followed the teacher's guide.

Bill's expertise and his desire to advance it are in contrast to the initial reasons of other teachers for joining these efforts.

None of the other teachers had previous project-based science experience, and few were familiar with telecommunications technology. Their motivation for learning most often was related to a desire to enhance student motivation and learning in science. In contrast, Bill may already have come to a conclusion about the merits of project-based instruction, about how to do it, as well as its limitations, so that he did not share his peers' focus on students' reactions or concern with learning new strategies for enactment. He was aware of the discrepancy between his beliefs and practices, citing problems of maintaining order and of students' lack of skills for autonomous learning. Instead of focusing on strategies for helping students learn to benefit from increased autonomy and for managing that in his classroom, however, he focused on telling others in the project what he already knew.

Collaboration and Technology: George

At the beginning of his nineteenth year of teaching, George's district science coordinator suggested he join our project. He was reluctant, stating later that "basically, I was talked into it." He was concerned that the science projects would take time from the district curriculum. The year's first meeting reassured him; George wrote in his case report that the content of *What's in Our Water?* and *Acid Rain* "fits right into the curriculum."

A second concern was his personal life. George's teaching assignment had changed several times in recent years, and preparing new material frequently took considerable effort. He wrote, "the amount of preparation and time limits as well as unforeseen problems could stop most people. It almost stopped me before I started the program . . . I was very interested in time involvement."

Nonetheless, he was looking for new approaches. So, despite continuing reservations, he decided to participate. George had little experience in using computers but wrote in his case report that "I feel that I should become more computer literate than I am because they [students] take classes in computers at our school. And I feel that . . . even though I've used computers in the past . . . still, I haven't tapped into its whole potential." George also faced the challenge of students working collaboratively. He acknowledged that changing from a teacher-directed lecture format to using student groups created some tension, which he described as "mental drain." Although George advocated the use of hands-on activities, he was concerned about covering content; that students followed procedures correctly, got "right answers," and completed tasks; and that the classroom was orderly and quiet. He commonly had students read lengthy directions aloud and sometimes distributed two to three worksheets daily. George had two challenges: (1) how he would learn to use the technology for his instruction, as well as for student investigation, collaboration, and artifact development, and (2) how he would promote collaboration by establishing groups and norms, sustaining focus on a problem, and holding students accountable for participation.

The setting. George taught eighth grade in a middle school in a working-class community with a population of about 40,000 in southeastern Michigan. The community is home to a large state university and several automobile plants and is suffering economically because of plant closures and related business loss. The student population is mixed, with a large percentage of African Americans. George's classroom had a permanent demonstration table along the front of the room and counters along one side and back. His desk was pushed up against one end of the demonstration table and was piled high with papers and materials. A storeroom/office off the classroom was filled with equipment. Pairs of students sat in rows facing the front.

Students changed science teachers at the midyear break. Thus, George taught an entirely new group for the second project. His

classes ranged from 18 to 24 students. There were many mainstreamed special education students in each class (from 25%–35% per semester), and one of the classes had a special education aide who circulated around the room monitoring the students and providing assistance.

Initial attempts at project-based instruction. George's first priority was becoming comfortable with technology. His case report reflects apprehension about logging onto the computer network: "I got all the material together and sat down to go through the program. I was loaned a computer and found that there were problems with the hardware working right. I spent much time trying to get things to go right while meanwhile watching the deadline date approaching. I found anxiety starting to rise. . . . The last thing I wanted was for the program to flop before it got off the ground."

This concern with his competence was reasonable and reflects one of the difficulties that teachers who are inexperienced with technology might face in enacting project-based instruction. If the telecommunications did not work—and George could not predict whether they would—he would be left in a quandary. A teacher in such a position is not able to control events. At least, when teaching in the traditional manner, George had alternatives ready to use in case of a breakdown in an activity.

In such a situation, George used familiar strategies. When he introduced the telecommunications software to the class, he started with a lecture and involved students only minimally. During the first lesson of the water project, George asked a student to sit at the computer at the front of the room. George presented a brief description of the hardware and the telecommunications network to the class. ("It is called an electronic post office. . . . We are sending letters to this post office . . . so each one will be sending it in. . . . We will be picking up our mail from this postbox.") George did not explain how modems functioned or how the letters were sent electronically and stored in a computer.

As George demonstrated the software, the students watched the large screen. He pointed to the features of the menu and directed the boy to click the cursor on each selection. When showing the mapping features, one boy asked George whether they could zoom in on other countries. George told him that they might do that later, if time permitted. When George showed the locations of network schools (Racine, Virginia Beach, Los Angeles, Honolulu), several students appeared more interested. George ended by saying that students had to know where their water came from and that they had to send the information to other schools on the research team. He focused on time pressures ("we can't drag our feet on this") but did not indicate the importance of the information or how it would be used to understand key issues.

In this first lesson, George was clearly interpreting the demands of project-based science by using a frame of reference with which he was familiar. During the first work session in the fall, the collaborating teachers were shown the functions of the telecommunications software and how to log onto the network. In addition, they learned how to assemble the computer, modem, and printer and how to use a large-screen monitor for whole-class presentations. Teachers were encouraged to work in collaborative groups, cycling between several different work stations. The model presented in the work session was that of group interaction and hands-on experiences in using the software and the water project activities. This early work session had little effect on George's initial attempts, beyond the content related to the technology.

At a work session near the end of the project, teachers discussed how students could make sense of the team and national data. They considered strategies for using collaborative student groups to analyze and interpret data. Nevertheless, George chose not to analyze and interpret data with stu-

dents; he did it himself, using the computer as an aid. He showed the network data to the class by using the monitor and an overhead projector plate and had students enter the information on worksheets. George told the students, "We are going to be dealing with the information of every one of the schools, every one of the teams. National Geographic network is sending all that stuff to us by way of the phone line, and we should be able to analyze it through the United States." The students listened quietly as he commented on the data, identifying trends and illustrating information from different areas. Thus, although George had mastered the technology, he had not yet learned to use it to enhance student learning. Experiences and strategies discussed during the work session had limited effects on his teaching.

George also faced the dilemma of engaging students in collaboration while maintaining order and covering the curriculum. In the first interview early in October, George said he would like to arrange his class into small groups of three or four students. In such groups, students would be involved and could help each other. The teacher's role would be as a facilitator, moving among groups to monitor engagement, pose questions, and propose or recast problems for students.

There were three barriers in George's mind to achieving this scheme: (1) he lacked space and equipment; (2) it would be impossible to cover the curriculum because "you can't do it all. When you try to do a project, accountability is a problem"; and (3) many of his students "lack the maturity" to profit from such an arrangement. Nonetheless, George did try to use some small-group activities throughout the first project. Indeed, his approach to these activities was much like he envisioned, except that the focus was on dividing tasks and completing the work correctly rather than on students sharing ideas. George devoted considerable energy to distributing and managing student folders and lab materials. He arranged students in groups and moved among them, monitoring on-task behavior and progress. The work, however, consisted largely of completing worksheets or other constrained tasks. He assigned group members roles and provided extremely detailed directions, which sometimes took 15 minutes to present to the class. Group members worked together primarily to understand directions in order to do experiments correctly. There was little, if any, discussion among students about the purpose of the activity, the reasons for procedures, or the meaning of data.

The second project. Between the two projects, the work session included additional use of telecommunications. In addition, several teachers discussed their students' enthusiasm for writing the letters to the network schools. When George introduced the *Acid Rain* project during the second semester, he decided to make it a "multimedia event." "I had the computer hooked to a monitor as well as the telex on the overhead projector." In comparison to the water project, this presentation included much richer information on the benefits of technology. He described how modems work and how signals are transmitted, and he demonstrated how letters are sent and picked up. However, despite having heard from others about student enthusiasm for writing and transmitting the letters, George once again sent the data over the network himself. He also did not discuss how technology use could contribute to understanding the driving question.

George continued to show students how technology works but did not involve them in its workings. He demonstrated an electronic bulletin board on weather data, which, although not part of the acid rain project, was introduced in one of the collaborative work sessions in late fall. He used the software to answer students' questions about weather conditions around the country but did not relate these to issues of acid rain. Similarly, a few weeks later George passed out copies of letters that had been

downloaded previously from the network. The students plotted the location of the network schools on individual worksheets rather than using the computer for this purpose.

In the final lesson of the *Acid Rain* project, the computer was at the front of the classroom, this time linked to two large-screen monitors rather than one monitor as in the past. George told students they were going to go over the international data. The presentation was more technologically complex, but George interpreted the data himself rather than let students grapple with the issues. He used the electronic map to highlight California, showed data on Japan, and retrieved 3 weeks of relatively consistent pH data.

Moreover, George's use of collaborative groups changed little during the second project. He continued to focus on students conducting specified procedures with assigned roles and finding correct answers. The essential nature of collaboration—exchange of ideas related to the driving question—was not achieved.

Conclusion. Over the year, George's mastery of technology improved considerably; his presentations were smooth and drew on a variety of software packages. However, he did not incorporate additional aspects of technology into projects; he did not instruct students in its use or grant them autonomy to use it for learning. His focus on curriculum coverage, correct procedures and answers, and order limited his attempts to promote student collaboration to assigning roles for the purpose of task completion rather than to promote thoughtful engagement with ideas. When students worked together, and when he used technology to create a "multimedia event," George continued to maintain control over content by interpreting data and linking ideas.

Summary and Conclusions from the Four Case Studies

The four case studies reported in this article demonstrate the range of practices these teachers used as they learned to enact project-based science. Each teacher made sense of the innovation in terms of his/her already well-established frame for teaching. In Shulman's (1987) terms, the teachers' learning about project-based science could be characterized as a "dialectic." They came to understand the innovation by moving back and forth between the new language and practices and what they already understood about teaching.

Challenges

There were commonalties in the teachers' approaches to learning about and enacting the innovation. Each teacher's focus was based on her or his primary reasons for joining the effort. For some, the reasons were fostering student motivation to learn science and enhancing students' cognitive engagement with science content. These teachers were drawn to challenges involving student ownership of questions and collaboration. Their early attempts to develop student ownership involved fostering student autonomy in activities and investigations and encouraging students to take responsibility for their learning. Similarly, teachers saw collaboration among students as a key to generating students' involvement in project-based science. High involvement is a sign of motivation, and, as Prawat (1992) pointed out, many teachers believe that involvement indicates thoughtfulness. That is, since thoughtfulness requires involvement, involvement is a sufficient condition for fostering thoughtfulness.

Moving past their conceptions of collaboration as involvement meant that the teachers had to form views of collaboration that included more than students sharing work or dividing responsibilities for conducting predetermined tasks. Collaboration requires exchanging ideas and negotiating meaning. It is difficult to help students collaborate if teachers believe that the risk of failure to get the right answer outweighs the

longer-term benefit of developing coherent understanding.

The teachers were also motivated to learn the technology. Computer use in schools and computer-based telecommunications are popular issues in education, and it is understandable that teachers want to be able to use these technologies in their classrooms. As well, teachers recognize that many of their students are more knowledgeable and competent at computer use than they are, and teachers would like to keep up with their students. Thus, interest in the challenges associated with technology use was evident, particularly in the first project when the technology was introduced. What was more difficult for these teachers was to move beyond the use of technology as an instructional aid to using it as a cognitive tool, what Salomon, Perkins, and Globerson (1991) refer to as "partners in cognition." This more constructive use of technology was clearly hampered by limited resources (e.g., few computers, inadequate space, and short class periods with little scheduling flexibility). But, more important, it may be impossible to help students understand the uses of technology as a cognitive tool if teachers do not use the technology in such a manner. For three of these teachers, the technology was relatively new, and, consequently, they did not yet realize its potential for their own and students' learning.

Perhaps one of the most critical challenges for the teachers was learning to use the driving question to orchestrate a project. For many, this idea might have been the most alien of all, for it is premised on the notion that students' construction of understanding is based on exploring answers to authentic problems that contain worthwhile science content. Although many teachers might subscribe to this notion in the abstract, when it comes to organizing curriculum around it, problems become evident. Many teacher questions arise: What if I don't cover all of the concepts and facts in the curriculum? What if students come up with questions about topics I know nothing about? How do I maintain order in the classroom if different groups of students are working on different investigations? How do I justify to parents a program that might not lead to higher achievement test scores?

Developing instruction around driving questions instead of basing it on the topical structure of a discipline is indeed a different idea, as John Dewey found out almost a century ago. Moreover, it requires teachers to view the curriculum as a dynamic set of ideas to be explored rather than a fixed set of ideas to be transmitted. Researchers are increasingly interested in the role of content knowledge in fostering teaching for understanding (Mosenthal & Ball, 1992; Shulman, 1987). The case studies here suggest that the teachers' content knowledge clearly played a role in their enactment of project-based science.

Enactment

The teachers faced common problems in enacting both projects. One such problem was time (Wilson, Miller, & Yerkes, 1993): How could they get through the curriculum and adhere to the deadlines? There never seemed to be enough time to do each activity well, and the teachers often had to end an activity with no follow-up. Some teachers did have the flexibility of double periods or teaching the same class a different subject so that they could use the extra period to work on the project. But they still worried about time. When class schedules were not flexible, all four teachers encountered occasions when they could not continue an activity and could not leave materials out because other classes used the room.

The second problem that the teachers faced concerned incorporating their project-based science work into the district's curriculum guidelines. Some worked in districts where administrators, other teachers, and parents expected all teachers to follow the guidelines closely. Such situations exacerbated the dilemma between content

coverage and student freedom to explore ideas. The dilemma was also heightened by the fact that we began with published curricula as a common starting point for teachers. If prepared materials are to be used, it is important that they articulate well with the district curriculum framework.

A third problem all teachers faced was the need to maintain order. There are three issues to be considered when teachers focus on maintaining order. The first is the ubiquitous need to maintain social order so that the classroom does not degenerate into chaos. Of course, although order is a necessary condition for social discourse, it is not a sufficient condition for learning. This leads to the second control issue, which is that teachers try to maintain order so that all learners are engaged in similar classroom tasks. This issue is more directly related to learning outcomes than the first, but it is based on a conception of teaching and learning that presumes that students' cognitive processes in classroom learning can be known and guided or controlled (Winne, 1985). This teaching practice is more akin to behavioral or information-processing theories of learning—which suggest that learning is hierarchical and that students need to learn facts before concepts and concepts before problem solving—than to social-constructivist theories.

The belief that order needs to be maintained to control students' cognition is not far from the belief that cognition needs to be supported as students develop competence at new learning. This belief is related to the constructivist concept of scaffolding instruction, where teachers initially maintain tight control as they model processes and coach students through complex intellectual tasks before granting responsibility to students. In fact, these teachers were often unwilling to let go. They voiced concern about students' inability to handle responsibility, their lack of awareness of their learning problems, and the need to direct their learning.

However, the teachers sometimes contributed to the situation they feared. That is, in their desire to foster ownership and collaboration, they often gave students too much responsibility. As a result, when granted autonomy, students were often ineffective; they failed to collaborate effectively, did not discuss the meaning of ideas, and did not stay focused on the driving question. Unfortunately, this reaffirmed the teachers' beliefs that the students could not profit from this independence. The teachers were unaware of the amount of time it takes to create a community of learners and abandoned their efforts prematurely.

Another issue concerns the teachers themselves and relates to their personal need to have the classroom under their direction. The range of motivations for this behavior may be considerable, from power and authority issues to vulnerabilities due to lacunae in the teachers' backgrounds. For example, Clark and Peterson (1986) found that some teachers persist in unproductive approaches to teaching, even in the face of evidence that the approaches are unsuccessful, merely because they have no knowledge of alternative approaches. Our model of teacher learning is based on our belief that, given appropriate learning settings and support, teachers can develop new views of teaching and learning and persist at making changes in the face of difficulties.

Finally, the teachers found that attempting to enact one feature of project-based science inevitably involved problems with other features. For example, some teachers tried to focus on collaboration or investigation but found that they had difficulty maintaining their own and students' attention to the driving question. Or some focused on using technology for instruction but were unable to foster students' use of technology to create artifacts.

Change

Our ultimate goal was for teachers to emerge from their collaborative work with

knowledge about how project-based science classrooms look and work. To do this, teachers needed to have conceptions of the features of project-based science and strategies for their enactment. The teachers approached the year's work with similar concerns: a desire for their students' motivation and learning and an interest in enhancing their own competence. Each teacher's persistence was sustained by a combination of factors: the challenge of enacting the features, the nurturing work sessions, and the increasing sense of efficacy associated with students' growth.

Collaboration among teachers played a critical role. The teachers first used collaborative activities to acquire information about project-based science, to learn how to use the technology, and to explore the content of the two projects. Once teachers trusted one another and had some experience enacting projects, they began to discuss their work. These discussions validated each teacher's experiences, vividly portrayed the possibilities and difficulties of project-based science, and encouraged the teachers to experiment and tailor the projects to their own contexts.

Summary

We began this work with a set of premises about how students and teachers learn. To be faithful to these premises, we employed the idea of a range of congruent practices. That is, we felt then, as we still do, that teachers' learning is best facilitated by encouraging and supporting teachers to reflect on their practices and to attempt to change through enactment and collaboration. We presented our conception of project-based science as a way to think about innovative instruction. We did not, however, present this innovation as a method; rather, it was based on a set of concepts with possible means of enactment. What we predicted would be critical, and what proved to be critical, was that the potential of project-based science could be realized only through teachers' enactment of science projects. Their understanding took the form of practical, not theoretical or propositional, knowledge.

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